Data Mining and Complex Systems Design for Integrated Systems Health Management (ISHM)

The Ames Data Mining and Complex Adaptive Systems Group supports ISHM in three ways: by using anomaly detection algorithms for fault detection, by using data mining for prognostics, and by using distributed adaptive control for self-maintenance and recovery.

Background

Data mining seeks to discover previously unknown regularities or anomalies in large data sets. The Data Mining and Complex Adaptive Systems Group in the NASA ARC Computational Sciences Division has extensive experience in data mining research and applications. Here we describe two ways in which we can apply data mining to ISHM. Additionally, we describe how we can design complex distributed systems to continually adapt to changing conditions to both avoid and recover from faults.

Data Mining for Fault Detection: We are developing methods to automatically detect unusual or anomalous data in either historical or real-time sensor data, so that people can direct their attention to the unusual data. Our work includes both supervised (using examples of faults) and unsupervised (using only nominal training data) approaches. These methods can also be used to help construct monitors for use with a model-based diagnosis system such as Livingstone.

Data-Driven Modeling for Prognostics: Prognosis of future failure states and predicting the type of failure is extremely difficult due to the high dimensionality of the problem. The number of relevant dimensions for prognosis of spacecraft failures is in the tens of thousands. There are several scientific approaches to prognostics including data-driven, physics-based, and statistical approaches. We use a variety of advanced real-time data mining techniques that incorporate model-based information with sensor data to identify potential precursors of failure. Using these techniques, we can forecast trends and potentially anomalous behavior based on real-time information.

Figure 1: Fault Detection

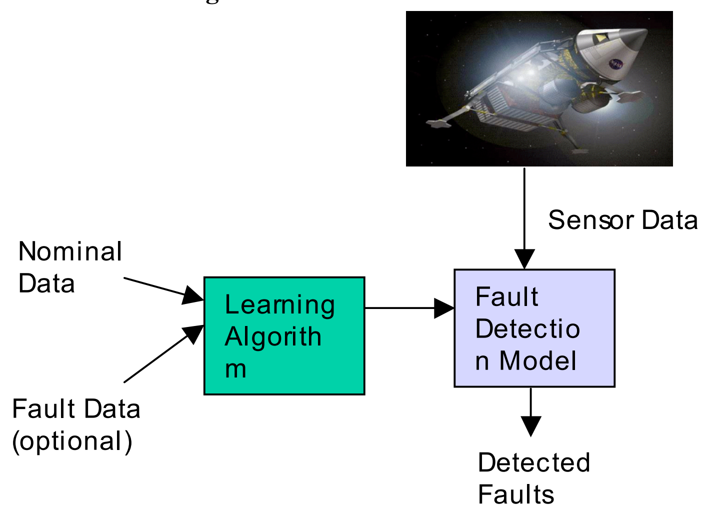
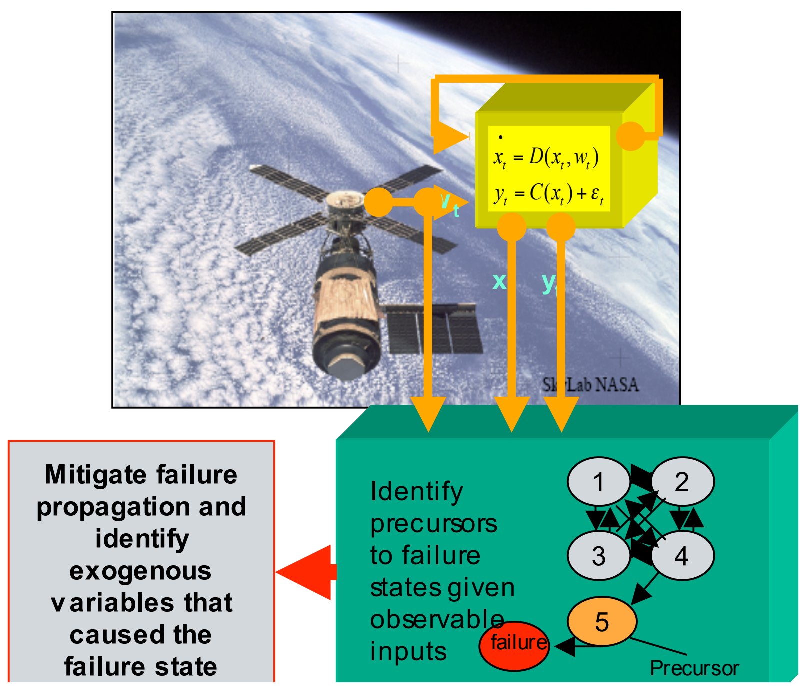


Figure 2: Prognostics



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Adaptive Control and Recovery: Sustainable space exploration requires more reliable and adaptable systems, particularly for missions with significant component degradation such as lunar robots or for prolonged missions like Jupiter Icy Moons Orbiter (JIMO). Traditional systems which provide redundant components improve robustness, but increase complexity, are costly and wasteful, and provide limited adaptability. In contrast, modular system-of-systems (SoS) architectures provide a firm basis for sustainability through modular, reconfigurable component designs. To reap the maximum benefit from such architectures, *intelligent adaptive systems must be combined with modular designs to provide inexpensive, reliable, and reconfigurable space platforms which are self-(re)configuring, self-maintaining and self-healing*.

Research Overview

Fault Detection: Orca is one of the anomaly detection tools developed in our group. It uses a nearest-neighbor-based approach to unsupervised anomaly detection, defining a point to be an anomaly if its nearest neighbors in feature space are far away from it. It uses to novel pruning rule to achieve nearly linear time performance. This high speed is essential for ISHM applications that require a large volume of sensor data to be processed in real time. Orca has previously been used in Earth science applications, where it successfully detected previously unknown errors in data from Earth-observing satellites. It has also been applied to aviation security data.

Adaptive Control and Recovery: Recent advances in multi-agent coordination methods may be leveraged to maximize system-wide sustainability by treating subsystems within any generic system-of-systems (SoS) architecture as agents. When subsystems fail or mission goals change, adaptive agents representing the subsystems compensate by reconfiguring the parameters of, and interactions between, subsystems in a (semi-)autonomous fashion. Such compensations minimize the need for expensive human intervention, and can adapt in a timely fashion in time-critical scenarios when there are long radio delays. Additionally, by including humans as additional agents in the multi-agent system, variable levels of autonomy may naturally be supported. Further, because the system is distributed across agents (systems) there is no need for centralized control, and scalability is excellent. Generic reconfigurable, distributed, adaptable multi-agent-based SoS architectures may be applied to movement control systems on lunar robots, to power or propulsion

Relevance to Exploration Systems

Integrated system health management will be a key contributor to the safety, reliability, and affordability of future exploration missions. Data mining and complex systems design can be combined with other ISHM approaches to obtain higher ISHM performance at lower cost.

H&RT Program Elements:

This research capability supports the following H&RT program /elements:

ASTP/SISM; Health Management Technologies

TMP/ASPS; Integrated System Health Management

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